ONE-YEAR EXPERIMENT IN NUMERICAL PREDICTION OF MONTHLY MEAN TEMPERATURE IN THE ATMOSPHERE-OCEAN-CONTINENT SYSTEM

JULIAN ADEM and WARREN J. JACOB

Extended Forecast Division, NMC, Weather Bureau, ESSA, Washington, D.C.

ABSTRACT

The results of a 1-yr. experiment in numerical prediction of monthly mean temperatures using a time-averaged thermodynamic model are presented.

For the 12-mo. period from December 1965 to November 1966 the statistical evaluation of the prediction of anomalies of the mean monthly surface temperature over North America shows skill higher than persistence for each season, except for summer.

Similarly, the evaluation of the predictions of month-to-month changes in ocean surface temperature anomalies also shows skill substantially higher than that of a prediction based on the tendency to return to normal.

1. INTRODUCTION

In a series of papers [1–6] a time-averaged thermodynamic model of the atmosphere-ocean-continent system has been developed.

The basic equations used are those of conservation of thermal energy in the troposphere and in the surface of the earth. The equations contain the storage of energy in the ocean and in the troposphere, the horizontal transport of heat in the troposphere, the excess of radiation in the troposphere and at the surface of the earth, the sensible heat given off from the surface to the troposphere, the heat lost by evaporation at the surface, and the heat gained by the troposphere by condensation of water vapor in the clouds.

The model was initially applied to compute the zonally averaged climatological temperature distributions [1], [2]. Afterwards it was applied to the Northern Hemisphere with a realistic distribution of continents and oceans to compute the climatological monthly and seasonal distribution of midtropospheric temperatures and surface (oceans and continents) temperatures [3], [4] and a method was developed to apply the model to predict, for periods of a month, the departures from normal of surface and midtropospheric temperature as well as of precipitation [4], [6].

The input data for the predictions are the fields of midtropospheric and ocean temperatures for the previous month and the position of the snow boundary at the end of the previous month. The model predicts for the next month the anomalies of temperature in midtroposphere and in the underlying surface (oceans and continents), as well as the anomalies of heat of condensation (precipitation) over the Northern Hemisphere. The model also generates internally evaporation from the underlying surface, transport of sensible heat from the surface, and cloudiness.

The purpose of this paper is to present a preliminary evaluation of the long-range numerical weather prediction experiments carried out with the latest version of the model.

Monthly predictions have been made each month since December 1965, using Model No. 2, which is described in detail in [6].

2. PRELIMINARY EVALUATION OF MONTHLY TEMPERATURE PREDICTIONS OVER NORTH AMERICA

A verification of the predictions for the period from December 1965 to November 1966 will be presented together with illustrations of some of the better individual cases.

Although the model predicts in detail numerical values of temperature departures above and below normal, we will test only its ability to predict the correct sign of the departure from normal. Therefore, only two categories (above and below normal) will be considered in the evaluation. We shall compare the prediction by the model with that obtained using persistence as a control (i.e., using the sign of the anomaly for the previous month as the prediction). Furthermore, in the evaluation we shall consider only the area of North America shown in figure 1.

The results of the evaluation are summarized in table 1, which shows the percentage of signs (out of a total 42 gridpoints within the box of fig. 1) of monthly surface temperature anomalies correctly predicted by the model and by persistence averaged for the four seasons of 1966.

Table 1 shows the overall superiority of the model over persistence, especially in spring and fall, when persistence was very low. However, in summer persistence gave slightly better results than the model. The last column of the table shows the differences between the percentage of correct sign predicted by the model and by persistence.

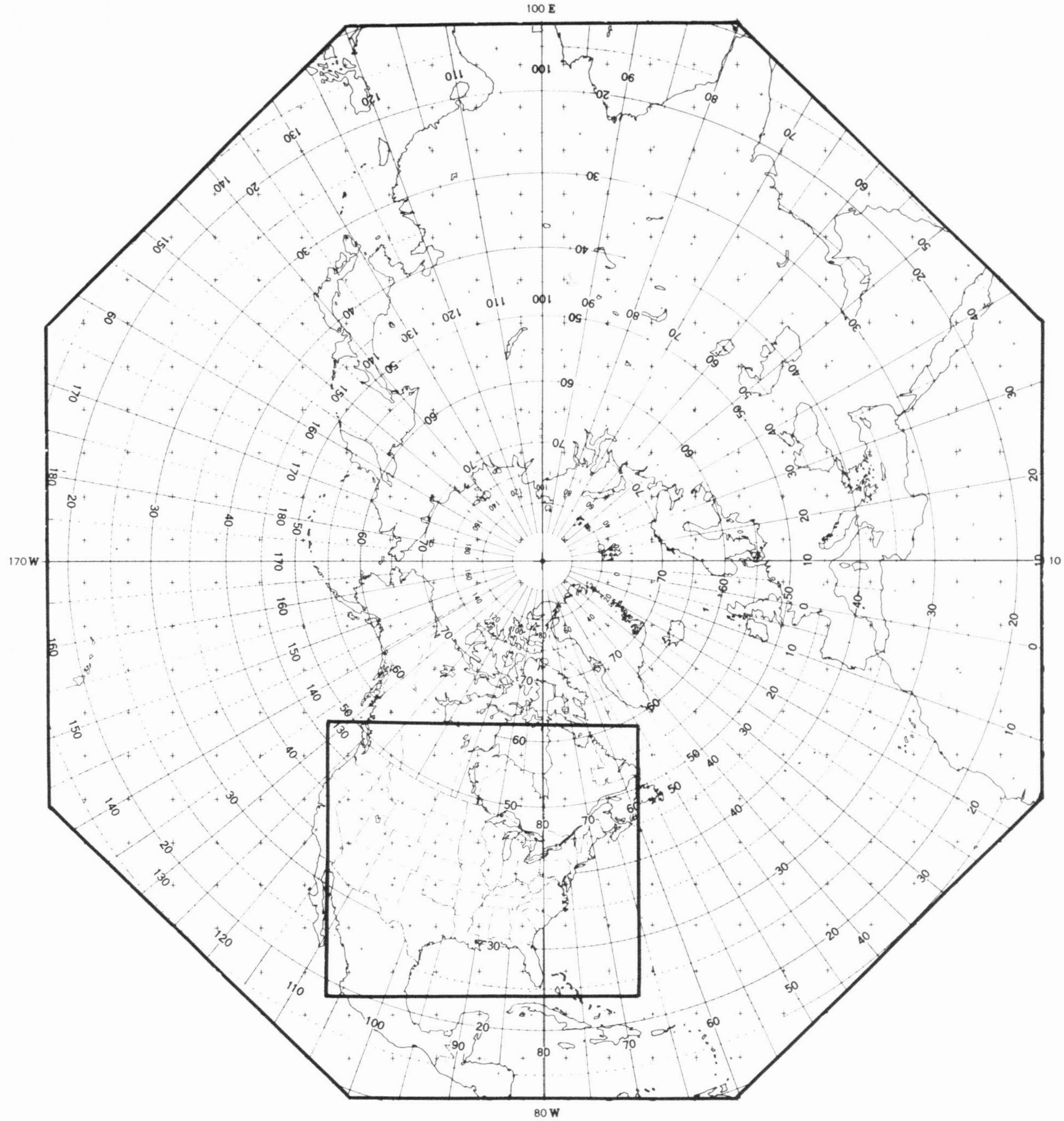

FIGURE 1.—The grid used by the model, with the verification area for air temperatures shown by the box.

TABLE 1.—*Percentage of correct sign of monthly temperature anomalies predicted by the model and by persistence, during 1966*

	Model	Persistence	Difference
Winter	55.5	51.6	3.9
Spring	51.6	44.5	7.1
Summer	52.4	53.2	−0.8
Fall	55.5	46.8	8.7
Annual	53.7	49.0	4.7

Of the 12 predictions considered, in seven cases the model was better than persistence, in three cases it was the same, and in only two cases was it worse.

Turning our attention to some of the individual months within the considered year, we have selected the February case, shown in figure 2, which indicates, in this case, the ability of the model to predict precipitation as well as temperature. Figure 2A shows the anomalies of the surface temperature (in °C.) predicted by the model and figure 2C those observed. Comparison of figure 2A with 2C shows good agreement between predicted and observed temperatures.

Figure 2B shows the predicted anomalies of heat of condensation (in ly. per day) and figure 2D the observed anomalies of precipitation over the United States, in three classes: heavy, light, and moderate. Comparison

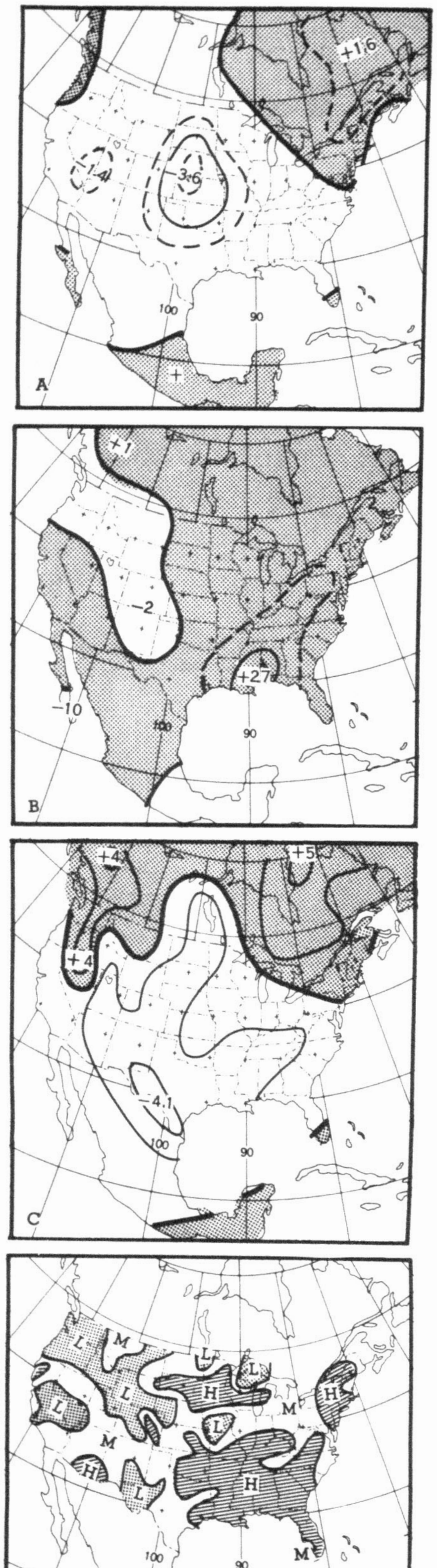

FIGURE 2.—Anomalies of surface temperature and precipitation for February 1966: (A) predicted temperature (°C.); (B) the predicted heat released by condensation (ly./day); (C) observed temperature (°C.); and (D) observed precipitation in three equally likely classes: Heavy, Light, and Moderate.

of figure 2B with 2D shows good agreement between the predicted above (below) normal heat of condensation and the observed heavy (light) precipitation. This crude qualitative comparison is obviously not suitable for quantitative verification purposes but rather is shown to illustrate the type of information obtained from the model which is available for predicting precipitation. In fact, figure 2B also shows that the values of heat of condensation predicted by the present model are smaller than those corresponding to observed amounts of precipitation.

The ability of the model to predict, in some instances, changes in the surface temperature is illustrated in the most striking way by the case shown in figure 3.

Figure 3A shows the observed anomalies of the surface temperature for March; figure 3B, those observed for April; and figure 3C, those predicted by the model for April. Comparison of figure 3B with 3A shows a sharp reversal in the observed anomalies; and comparison of figure 3C with 3B shows good agreement between observed and predicted anomalies, especially over the United States.

One of the major contributing factors for the success of the model in April was an extensive snow cover over northern United States whose boundary was south of the normal position at the end of March. The major role of the oceanic influence is also illustrated by the predicted thermal pattern over the east coast area. Of particular importance is the predicted -2.5°C. anomaly center which, according to the model, is due to colder than normal ocean water just east of that area, and which agrees well with the observed center of -1.7°C.

Figure 4 shows the August case. In figure 4A are the observed anomalies of the surface temperature for July; in figure 4B, those observed for August; and in figure 4C, those predicted by the model for August. Comparison of figure 4B with 4A shows a strong reversal and inspection of figure 4C shows that the model has predicted the reversal, but with anomalies much weaker than the observed ones. One of the major factors influencing this predicted thermal pattern was the above normal cloud cover generated by the model.

3. EVALUATION OF MONTHLY OCEAN SURFACE TEMPERATURE PREDICTIONS

In this section we shall verify the model predictions of the ocean temperature. In this case it is more meaningful to test the ability of the model to predict the month-to-month change in the anomalies instead of the slowly varying anomalies themselves. Furthermore, we will test only the ability of the model to predict the correct sign of the change of the anomalies.

As control, we shall use a predicted sign change based on a return to normal, which is made simply by reversing the sign of the previous month's anomalies.

Table 2 shows the percentage of signs of the month-to-month changes in ocean temperature anomalies pre-

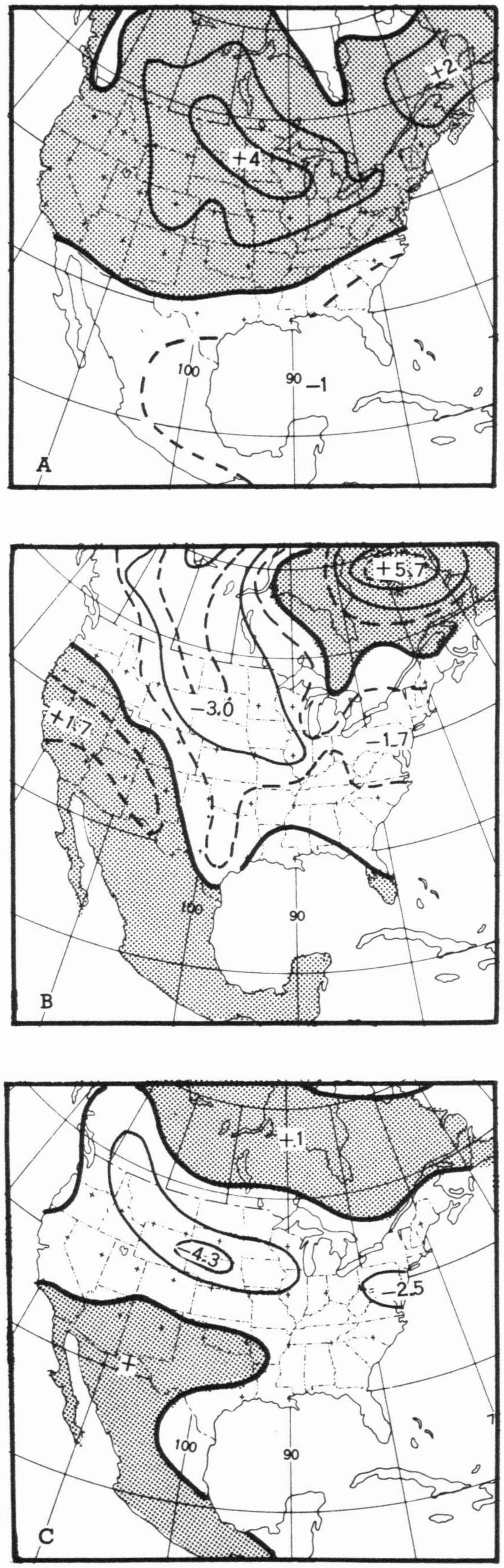

FIGURE 3.—Monthly mean anomalies of surface air temperature in °C. (1966): (A) observed for March; (B) observed for April; and (C) predicted for April.

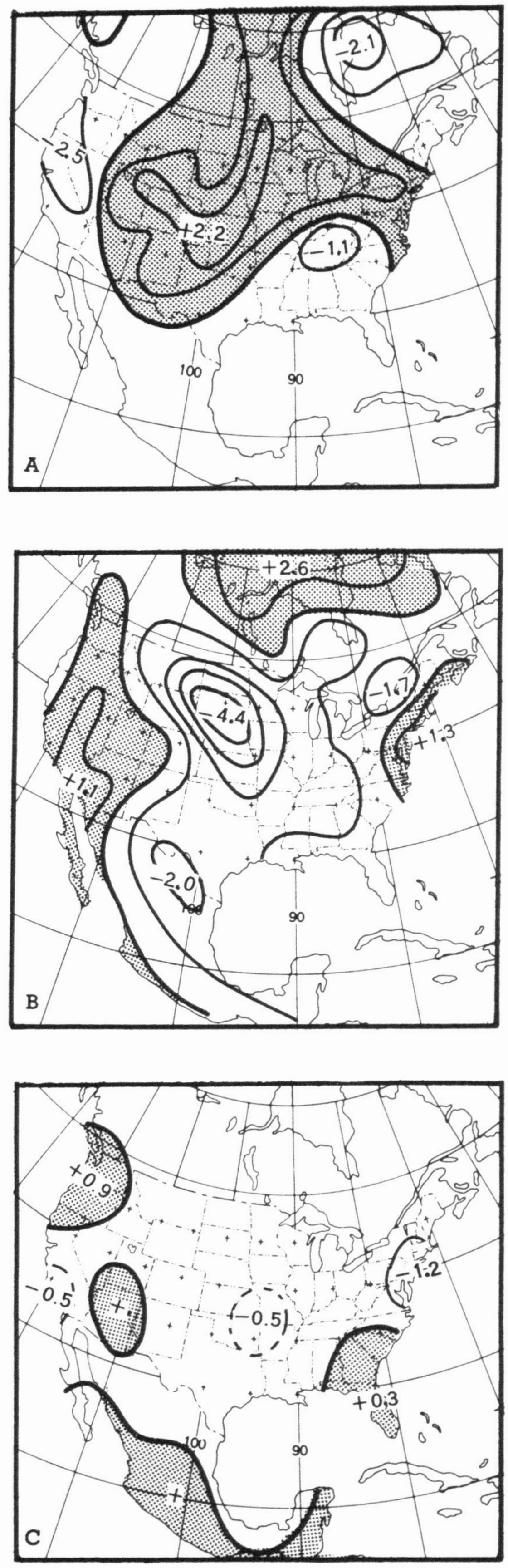

FIGURE 4.—Anomalies of surface air temperature in °C. (1966): (A) observed for July; (B) observed for August; (C) predicted for August.

TABLE 2.—*Percentage of signs of the month-to-month changes in ocean temperature anomalies predicted correctly by the model and by return to normal, during 1966*

	Pacific			Pacific and Atlantic		
	Model	Return to normal	Difference	Model	Return to normal	Difference
Winter	66.4	54.4	12.0	60.9	53.8	7.1
Spring	66.7	54.8	11.9	64.3	55.9	8.4
Summer	64.5	59.6	4.9	66.3	64.5	1.8
Fall	58.7	52.0	6.7	58.9	54.0	4.9
Annual	64.1	55.2	8.9	62.6	57.1	5.5

dicted correctly by the model and by return to normal for the 1-yr. period under consideration. Both the prediction by the model and by return to normal are considerably higher than 50 percent. However, the predictions by the model are substantially better than those by return to normal.

In winter, for the Pacific Ocean the percentage of correct sign predicted by the model is 12.0 percent higher than that predicted by return to normal; in spring, 11.9 percent; in summer, 4.9 percent; and in fall, 6.7 percent.

If we consider the Atlantic and the Pacific Oceans together, then the prediction by the model is 7.1 percent higher in winter, 8.4 percent in spring, 1.8 in summer, and 4.9 percent in fall. Furthermore, of the 12 predictions considered, in 11 cases the model was better than return to normal.

Figure 5 shows the prediction of the monthly change from March to April. Figure 5A is the change predicted by the model and figure 5B the observed change. Comparison of figure 5A with 5B shows that in the Pacific the model predicted not only the sign of the changes but also the position of many of the maxima and minima. Furthermore, the predicted change is of the correct magnitude although somewhat smaller than the observed change.

The case shown is figure 5 is one of the best predictions for the Pacific, having a score of 85 percent in that ocean.

4. FINAL REMARKS AND CONCLUSIONS

It is noteworthy that there is a certain degree of parallism involved in the skill of the temperature predictions over North America and that of the ocean temperature predictions. Comparison of tables 1 and 2 shows that the skill of both predictions is similar, being worst in the summer when the control has its highest value. This result applies to only 1 yr. of predictions and by no means ought to be generalized.

The above results suggest that long-range numerical weather prediction with a time-averaged thermodynamic model may be a fruitful approach to a problem which up to now has been attacked largely by empirical methods.

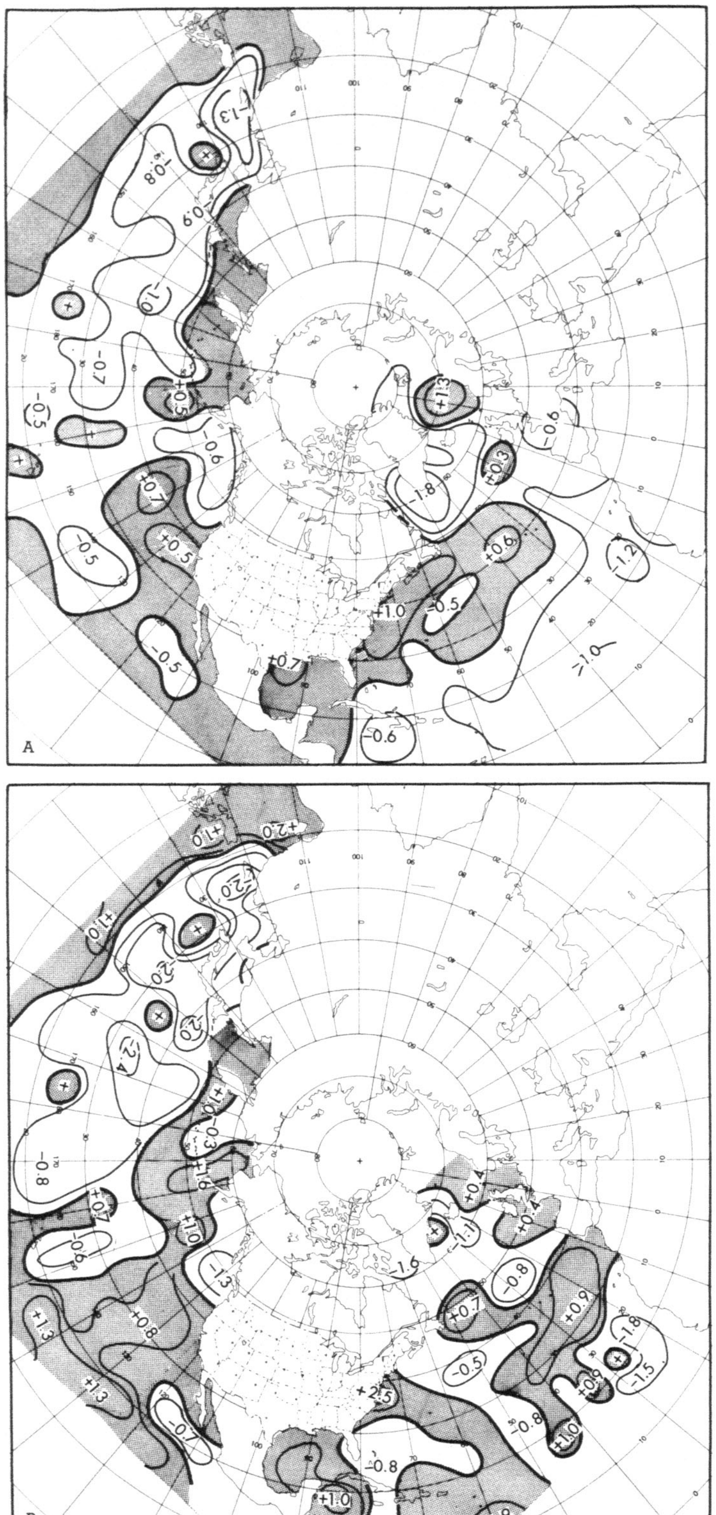

FIGURE 5.—Monthly changes of surface ocean temperatures from March to April 1966: (A) predicted by the model; (B) observed.

An important byproduct of the model is the prediction of monthly ocean temperatures. Despite the fact that the present model neglects advection by ocean currents, the predictions of surface ocean temperatures for 12 mo. had skill. It is expected that the inclusion of advection and the use of more realistic heating functions will yield a substantial improvement.

The neglect of the horizontal transport of heat by ocean currents is an approximation that has been used in the model since 1963 [2], mainly because it yields great simplification in the mathematical formulation of the model. The results of the numerical experiments suggest that this assumption is a good first approximation and that the vertical transfer processes, especially evaporation, play an important role in the prediction of surface ocean temperatures. This is, in fact, expected from the findings of several authors, among them Clark [7] and Jacob [8]. However, the above results do not imply that the horizontal advection is negligible. In fact, the work of Namias [9] suggests that its inclusion in any ocean temperature prediction model is essential.

A more elaborate model is now being developed that hopefully will improve the degree of predictability achieved with the present model.

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